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RESEARCH NOTES

TRUTH IN MODELING

Many scientists do not now embrace the concept of modeling. However, more forthrightness and shared information may increase acceptance. In creating an atmosphere of openness, the modeling community may reduce the number of people who are skeptical about or even hostile to models. Readers of modeling papers will be able to understand and interpret model outcomes, neither placing too much emphasis on the model's outcomes, nor too little. And, non-modelers may learn to work cautiously with models and view them as useful tools, accessible even to those who do not themselves create models. The burgeoning of web-based data products and web-based models (such as those using JAVA that can run on any platform) are factors that are improving the portability and accessibility of models. Models may even come to be sought for contributions to problem-solving in situations where they are not now commonly applied, especially in management decision-making.

Papers (and other documentation) about models are not always fully honest with the reader. Some contain model descriptions so incomplete or vague that independent checking of results is impossible. Occasionally this obfuscation seems deliberate. Possibly some authors set out to dazzle rather than to enlighten the reader. Model assumptions may be so hidden as to cloud the logic underlying predictions. Sometimes even the author seems unaware of this logic. Detail may be lacking. For example, some authors fail to specify units for model components. Careless use of symbols may unnecessarily obscure meaning, e.g., notation that jumbles normal mathematical symbols with computer code-like symbols. Such pitfalls should be avoided.

In order to foster clear communication among modelers, and between modelers and those who would use or read about models, uniformity in language is needed. Currently, terms such as *model*, *scenario* and *sensitivity analysis* may have different meanings when used by different authors. Until convention or some other mechanism sets standards, definitions should be included within each paper to establish the vocabulary employed. The modeling terms used in this paper are defined in Table 1. These definitions (Table 1) are not meant to be "set in stone," but rather to clarify how we are using the terms. Further, the definitions are intended to be broad enough to cover various kinds of models, both analytical and simulation.

In addition to well-defined terms having consistent meanings, transparent explanations are essential. Description of a model should have the objective of enabling another modeler/scientist to repeat the author's experiments (and replicate the results). Narration ought to illuminate interconnections within the model and lay bare its underlying logic. Adequate information should be presented to enable informed discussion, and criticism, of the model. If models are to be considered scientific, then there should not be "black boxes" for which the owner/maker has keys and everyone else must accept on faith. Modeling papers need a section analogous to the *Materials and Methods* in the typical scientific paper. However, one way in which model disclosures might differ from *Materials and Methods* is in desirability of mentioning and justifying things that were disregarded or omitted. Characterizing a model is similar to describing an experimental field site; the aim is to place the model on the landscape of possibilities. A modeler's reputation should not be depended upon to provide reliability for a model or any claims based thereon. Where to find source code or basic explication of models should be offered (possibly a reference to a website) to enable the use of the model by others. Doing one's own version of the code would be one way to "repeat the results," but recoding should only be necessary when part of the goal is to add further credence to the outcomes (multiple models increase the robustness of shared conclusions).

The act of modeling involves several phases; adequate attention needs to be devoted to all of them. Rather than being a linear process (Figure 1) the modeling activity ought to come full-circle (Figure 2). If the modeling activity has been linear rather than iterative, then the write-up will not be complete. Many modeling papers pay scant attention to interpretation and implications "back in the real world." Perhaps these areas are less entertaining for the creators of models, but they are essential to making models understandable and useful.

TABLE 1. Terminology as used in this paper.

Model	purposeful representation of fundamental characteristics of some real life situation or phenomenon.
Input	the particular values substituted for parameters in a model equation, and/or information entered into the computer at the time a model/program is executed.
Output	what the model provides after finishing the execution of a computer program, or the solution to a model equation.
Parameter	a numerical property or attribute, or a probability associated with an event or characteristic in a stochastic model.
Scenario	a particular set of parameter values, taken together.
Experiment	comparison of outcomes from two or more model scenarios designed to answer a particular question. (*Model* experiment as distinct from lab or field experiment.)
Stochastic	a model that has chance built in, and is thus unpredictable. In contrast, *deterministic* models have consistent, predictable outcomes.
Simulation	model structure that is designed to follow the essential occurrences in the real world. The operation of such a model is also called simulation.
Run	a single execution of a model computer program, using one set of inputs and providing one set of outputs. May be one or multiple replicates.
Replicate	a single simulation. When multiple replicates of a stochastic model are run, they differ only in the random numbers used; all model parameters and other settings are identical. Each replicate is an example of a possible outcome, sampled from the universe of all possible outcomes.
Sensitivity Analysis	an exercise intended to indicate which of the model's parameters is/are the most influential. The purpose is to answer, "How sensitive is the output to alterations in specific parameters?"

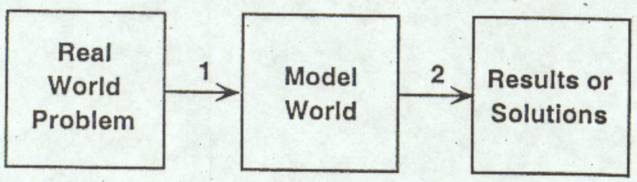

FIGURE 1. Linear mode of modeling.

Phase 1: Create a model world containing a purposeful representation of the problem. Manipulate the model.

Phase 2: Report outcomes. Draw conclusions from the model world.

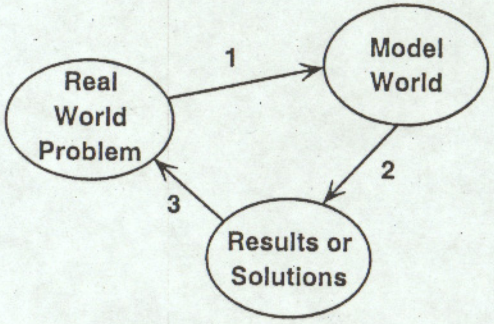

FIGURE 2. Iterative modeling process.

Phase 1: Create a model world containing a purposeful representation of the problem. Manipulate the model.

Phase 2: Report outcomes. Draw conclusions from the model world.

Phase 3: Relate the model results back to the real world. Reconsider whether the model formulation is satisfactory.

The following "Proposed Protocol" is a *checklist* for authors, reviewers and editors. The points are not intended to be rigid constraints, nor specifically sequential. They are *guidelines*, a sort of measuring stick, to see whether a modeling paper is complete. And they are preliminary. We want to initiate change, both among modelers and among

the editors and reviewers of publications which carry modeling papers. We invite your input. We wish to spark thought, seeking agreements, alternatives, comments, criticisms, additions, questions, etc. We desire discussion and hope to motivate a transformation in the practice of fellow modelers. To that end, please send responses as indicated in Table 2. A future paper will summarize the consensus of the feedback provided.

Proposed Protocol for Model Disclosures

1. Statement of purpose.

Problem or question(s) to be addressed. Why was the model created? Who is the intended user of the model or audience for the model results? If a standard model is being used, why is it appropriate to the problem at hand?

2. List of assumptions.

A complete declaration of necessary assumptions. Has a rationale for the adoption of particular assumptions been provided? To what extent has convenience been the deciding factor?

3. Structural or design information.

Classification or characterization of the model. Is it age-structured, individual-based, event-driven, a map, statistical, analytic, computer-based, or what? "As in so-and-so" is satisfactory only if that paper gave complete information. What modeling "platform" (akin to special equipment in standard experiments) was used? Is the model the simplest possible under the circumstances? How has Occam's Razor been applied?

4. List of variables, parameters, and relationships.

Complete list of components and a clear statement indicating how they are related. Why were specific functional forms and other model structures adopted? How was model parameterized? What were the sources of data? What degree of uncertainty is associated with the parameters? What units of measurement were used? Was consideration given to nondimensionalization of the variables?

What time and space scales were selected? Have both the time horizon and the time steps been specified?

5. Decisions, features, uniqueness, weaknesses.

Mention any special features or additions to standard models. In what way is the model unique? What alternatives in approach were considered and rejected? Is there an historical precedent to this model? Is it related to some other model? Have cautionary notes regarding any possible weaknesses of the model been shared?

6. Sensitivity analysis.

Ranking of parameters by influence. How was the sensitivity analysis performed and what did it reveal? Were there any parameters *not* analyzed?

7. Validation.

Testing, confronting the model with data. Has the model encountered data? What lends the model credibility? How do model outcomes compare to reality? What has been done to establish reliability? Why is the modeler convinced that the results are believable? Why should readers accept the model results as plausible? If a check of model predictions against reality was ambiguous, what was done to explore the range of possible outcomes?

8. Scenarios.

Combinations of parameters and inputs. Has enough specific information been provided to enable duplication of modeler's experiments or replication (in the sense of traditional science) of model results?

9. Outcomes, interpretation.

For analytic models, the "solution." What has been learned about the "model world?" What is the appropriate utilization of the outcomes? What sorts of measures were used to draw conclusions? Has the model been useful in generating hypotheses (if so, what hypotheses)? What can be said about transferability of the results? What generalizations may be made? What possible alternative explanations or conclusions might hold?

10. Real-world consequences.

Relating the implications to the "real world." How robust are the decisions based on model outcomes? Under what circumstances might model predictions apply? What future directions are suggested for further modeling or further research in other aspects of the question to which the model applied?

TABLE 2. How to submit a response to the proposed Model Disclosure Protocol.

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